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ABSTRACT: The aim of this work is to develop a new hyperelastic and anisotropic material mimicking histological and mechanical features of healthy and aneurysmal arterial tissues. The target material is constituted by rhombic periodic lattices of hyperelastic fibres embedded into a soft elastomer membrane. Based on a previous theoretical work yielding to an optimized microstructural arrangement and mechanical behaviour, this study provides experimental advances concerning the manufacturing of new fibrous membranes. Their mechanical characterization under various loadings is presented.

1. INTRODUCTION

Human abdominal aortic tissue is a complex cylindrical soft sandwich structure, arranged in three different concentric layers. Each layer is characterised by specific histological features, with different associated mechanical properties [1]. Previous tensile testings conducted on excised aortic specimens have evidenced the highly non-linear and anisotropic mechanical behaviour of human healthy abdominal aorta (AA) and aneurysmal (AAA) tissues [2]. This behaviour is usually considered as essentially hyperelastic, the non-linearity of which is ascribed to the particular wavy architecture of the fibrous structures which tend to straighten along the loading direction when they are subjected to a mechanical loading: this provides the arterial tissues a macroscopic mechanical response exhibiting a typical J-shape. Besides, the preferred orientations of the fibrous architecture are responsible for the mechanical anisotropy of the arterial tissues.

During the last decades, several soft materials have been proposed in order to perform *in vitro* experiments using AAA synthetic analogues, either placed into vascular simulators [3] or inflated until rupture [4]. However, such materials are made up of homogeneous elastomers with isotropic material properties, which are very far from the anisotropic hyperelastic behaviour of aortic tissues [2] and from their fibrous microstructure.

Therefore, the aim of the present study is to design and characterize the mechanical behaviour of new artificial materials, able to mimic (i) the macroscopic anisotropic properties of AA and AAA tissues, (ii) their hyperelastic J-shape mechanical response, (iii) and their main histological features (multi-layers fibrous structure with distinctive fibre orientations).

2. METHODS

Optimal materials able to mimic human AA and AAA hyperelastic anisotropic behaviours have been identified in a previous theoretical work using a multi-scale homogenisation process combined with microstructure optimisation [5]. Target solutions consist of bi-layers fibrous structure composites, made up of two parallel fibrous lattices embedded into a soft hyperelastic membrane. Based on these results, several types of commercial fibres have been selected and their tensile mechanical behaviours were studied. A specific device dedicated to the manufacturing of periodic fibrous lattices and square composite membranes has been designed so as to control angle between fibres (θ_0), and fibre length (l_0), as displayed on figure 1 (a). In order to validate the manufacturing processes as well as the micro-mechanical modelling developed in [5], three kinds of fibrous microstructure have been elaborated, comprising respectively:

(i) A one-layer lattice of straight fibres, able to generate a macroscopic anisotropy;
(ii) A one-layer lattice of wavy fibres, able to generate a hyperelastic J-shape mechanical response;
(iii) A bi-layers lattice of straight fibres, inspired from the multi-layered structure of biological tissues;

The mechanical behaviours of these three types of composites have been characterized under various loadings using a uniaxial tensile-testing device. Microstructural architecture of each fibrous membrane was investigated by means of X-rays micro-tomography.

3. RESULTS AND DISCUSSIONS

Mechanical behaviours of the matrix material and seven individual fibres will be firstly presented. A high strength RTV Silicone elastomer dispersion (Applied Silicone Corporation) has been first selected as matrix material, due to its transparency, high deformability and specific physical properties allowing liquid injection moulding and room-temperature curing. Among the different fibres, a fluorocarbon fibre has been selected as an appropriate candidate to the design of the intended periodic lattices due to its non-linear behaviour. It has been used to elaborate the three types of composites described above, whose typical microstructure arrangement is illustrated on figure 1 (a).

Mechanical behaviours of each composite will be presented and discussed with respect to the individual fibre constitutive law. Figure 1 (b) shows a typical example of experimental Cauchy stresses measured as a function of elongation state, on four samples extracted from a one-layer fibrous structure composite with straight fibres. Two different stretching directions are displayed. The anisotropic behavior of the composite is demonstrated at the macroscale.

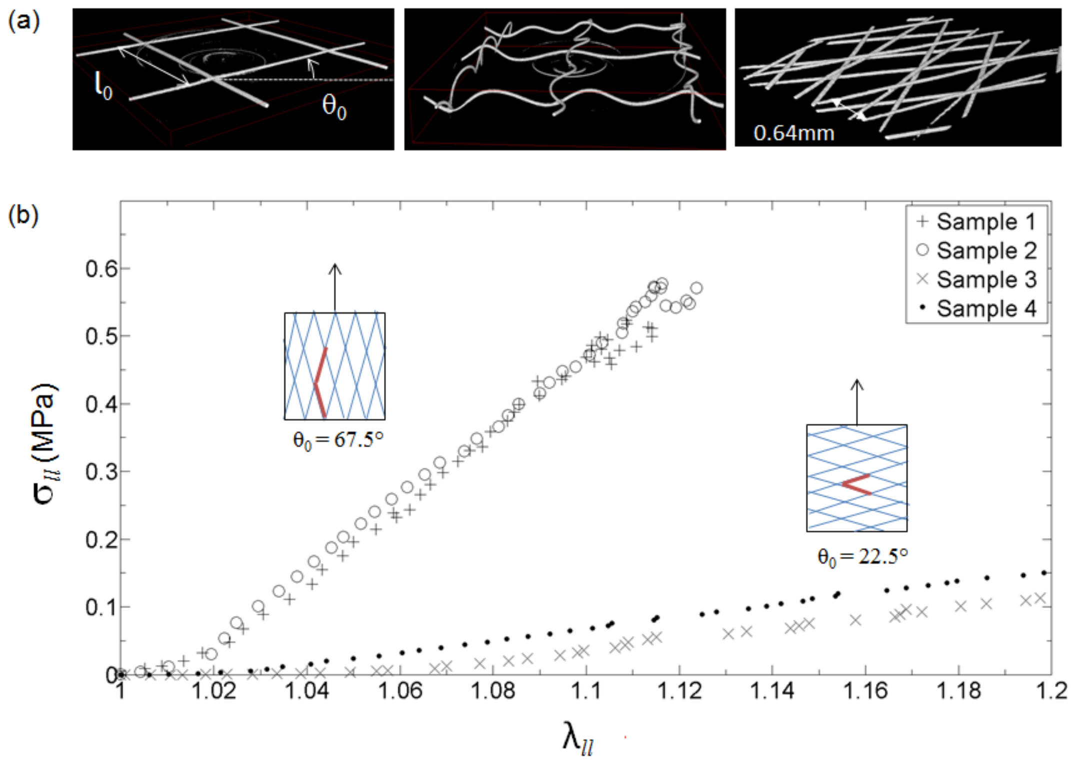

Figure 1 – (a) Typical 3D reconstruction of different periodic fibrous lattices characterized by X-rays micro-tomography: (from left to right) one-layer lattice of straight fibres; one-layer lattice of wavy fibres; bi-layers lattice of straight fibres. **(b) Mechanical behaviour of four samples extracted from a one-layer composite of straight fibres, stretched along two orthogonal directions**.

4. CONCLUSIONS

This experimental study presents several technical solutions to design one-layer and bi-layers fibrous structure composites. The control of a macroscopic mechanical anisotropy is allowed by changing two microstructural parameters only: the angle between fibres, and the fibre length. Particular cases of straight and wavy fibres are considered. These experiments represent an original database to validate model assumptions presented in previous work [5].

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